Research Proposal of the Thesis Entitled

‘Pervious Concrete in Urban Development: A Way Forward to Waste Water Management for Sustainable Growth’

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Abstract

This study is carried out with the objective of understanding the characteristics of Pervious Concrete with the intention to find out if it can pass as a sustainable solution for water wastage related infrastructural challenges posed by the exponential growth and development of the present. The study prescribes to the view that one of the most important factors for its success on field is its viability. Hence various aspects impacting the cost-benefit analysis of Pervious Concrete are to be studied through literature review of work done in this field. Once these aspects are listed down, primary research is to be conducted to gather data about the acceptability of Pervious Concrete as a choice of material by the stakeholders. The results of the study may be useful in developing comprehensive policies and regulations for the road construction and infrastructure industry as well ground water recharge management.

Keywords:

Sustainable Infrastructure, Green Infrastructure, Cost Benefit Analysis, Storm-water Pollution, Rainfall Pollution, Pavements, Storm-water flooding, Rain-water flooding, Ground-water Harvesting, Water wastage, Environmental Benefits, Cost, Storm water Harvesting, Water Sensitive Urban Design, Storm Water Management

Problem Definition

During the last few decades India has witnessed exponential urban growth and infrastructural development. Such growth and development invariably magnified environmental challenges if not complemented by innovative and sustainable solutions. The world is facing some common yet contradictory challenges like storm-water flooding /rain-water clogging and ground-water depletion due to urbanization. The infrastructural solutions and road construction materials used at present, concrete being the most common of all aren't ideal for managing rain water drainage. While on one hand the flooding causes not just movement restriction, productivity and material loss, on the other hand the ground water isn't restored as the water flows directly into the drainage system. The water-loss occurring out of such a set-up is so humongous; putting a number to it is an unachievable task.

To mitigate these two waste water challenges through a single solution, pervious concrete is being considered as an alternative choice of material for pavements and parking lots in various parts of the world during the last decade. In essence, Pervious Concrete is a zero-slump, open-graded material consisting of cement, coarse aggregate, admixtures and water. Pervious concrete contains little or no fine aggregates such as sand, it is sometimes referred to as "no-fines" concrete. Experiments are being conducted to arrive at an ideal design mix for the Pervious Concrete. Research is ongoing to understand the physical, biological, chemical properties of this material. Resulting information is being used to analyze whether it can become a viable choice of material leading to benefits to the environment and recharge of ground-water resources.

Research Questions

1. What is the water scarcity scenario in the country with respect to challenges and mitigation strategies?
2. What is the state of governance mechanism for ground water management in the country?
3. What challenges are faced in ground water recharge management at present that Pervious Concrete might to be able to mitigate?
4. What are some of the success stories world-wide towards ground water recharge due to the use of Pervious Concrete?
5. What kind of design-mix variations have been created and what have been the results of these experiments?
6. What work has gone into cost-benefit analysis of pervious concrete as a sustainable option for road construction and parking lots?
7. What are the kinds of costs to be considered and included in the calculation of cost-benefit analysis of pervious concrete?
8. What are the expectations of ground water management departments at state and central level from Pervious Concrete?
9. What are the expectations of the road construction and real-estate industry from a material of choice for pavements and parking lots?
10. What benefits can be reaped by using Fly-ash as one of the components of Pervious Concrete design-mix?

Literature Review

A detailed literature review was conducted to understand the research work done and results achieved for Pervious Concrete as well as related Green Infrastructure options available in different parts of the world. 40 articles/conference documents were collated and studied in the process. A brief record of the same has been narrated below.

(Guntakal & Selvan, 2017) Various experimental investigations related to aggregate investigation, effect of aggregate size and gradation, effect of aggregate properties, optimal mix, admixture investigation, optimum water to cement ratio, failure analysis with admixtures and without admixtures were performed.

(Tennis et al., 2004) reviewed the applications and engineering properties of pervious concrete pavements, its environmental benefits, its structural properties and its durability. It further discusses the hydraulic and structural design of pervious concrete pavements along with the construction techniques that may be used.

(Du et al., 2019) reviewed the research and analysis around the ongoing challenges related to storm-water management and concluded that low-impact development technologies like

rainwater harvesting, green roof and porous pavement are capable of replacing gray infrastructures and resolve the ongoing challenges immediately.

(Wang et al., 2021) conducted a systematic review of urban rainfall-runoff pollution control technologies in China based on bibliometric analysis and literature summary. Various insights on model and strategy, source reduction, process control and post treatment were found out and reported.

(Uthaichotirat et al., 2020) investigated the properties of lightweight concrete manufactured from high porous aggregates with phase changed material (PCM) added to it. These aggregates are the result of waste retrieved from the manufacturing process of autoclaved aerated concrete block (ACC).

(C. Li et al., 2019) discuss the operating mechanisms of some of the most widely-used Green Infrastructures (GI) with respect to storm-water management. They also examine policies for promoting GI implementation in countries like China and Australia and review the effectiveness of GI on treating storm-water quantity.

(Z. Li et al., 2018) conducted a systematic literature mining of Sponge city using 962 articles. Sponge City has attracted extensive attention in research due to increased threat of flood risk and environmental safety because of urbanization. The paper summarizes the past research, identifies research type and foci anticipating future research directions.

(Nalbandian et al., 2021) analyze the scientific evolution of self-healing asphalt pavements as one of the sustainable road materials based on SciMAT Analysis. The results show that self-healing asphalt technology has attracted a lot of research. Many techniques are being developed and various branches and niches have opened up in this research area and the scope for future research in this area is high.

(Chandrappa & Biligiri, 2016) investigate the mechanical-hydrological-durability properties of pervious concrete as narrated in various studies reviewed. Storm-water purification efficiency of pervious concrete has been documented and field investigations of some test sections of pervious concrete pavements have been discussed. A brief note on the life cycle cost analysis of pervious concrete has also been mentioned and scope for further research on same has been noted.

(Giustozzi, 2016) study the possibility of improvement in durability of pervious concrete by polymer-modification so that it can pass the test of a sustainable transportation infrastructure option. Four different polymers were tested and preliminary analyses on polymer-modified cement grouts and mortars were conducted. They were further tested to evaluate the inclusion of polymers based on type and content. Results showed increased mechanical resistance, durability to ravelling and freeze-thaw cycles. Polyvinyl acetate polymer turned out to be a good option.

(Singh, Vaddy, et al., 2020) provide a systematic lifecycle assessment (LCA) methodology to quantify the total embodied energy and greenhouse gas (GHG) emissions involved in construction of new pavement. A comparative LCA was then performed to adjudge the benefits offered by pervious concrete pavement (PCP) as compared to Portland cement concrete pavement (PCCP) for different mixing procedures and base layers.

(Dash & Kar, 2018) cover the comprehensive research program conducted by research group at KIIT Univeristy on fabrication of Fly-ash based Pervious Concrete (FPC). The results showed that the material has potential applications like ground water recharge, storm-water management, noise reduction, surface run-off control, temperature behaviour and pollution retention sinks.

(Nemirovsky et al., 2013) presented research designed to fill the knowledge gap in evaporation behaviour of Pervious Concrete Storm-water Control Measures (SCM). A laboratory simulation to identify evaporation affecting parameters was conducted and evaporation rates typical for summer months in Philadelphia were obtained.

(Singh, Sampath, et al., 2020) review in detail the various sustainability benefits of Pervious Concrete as discussed in literature and documents the current state-of-the-art with respect to mechanical and hydrological characteristics. Impact of pore morphology on permeability was examined and a note on current rehabilitation techniques for restoring infiltration rate of clogged PC surface courses was made.

(Sonebi & Bassuoni, 2013) studied the effects of water-to-cement ratio (W/C), cement content and coarse aggregate content on density, void ratio, infiltration rate and compressive strength of portland cement pervious concrete (PCPC) using statistical modelling. The methodologies used were two-level factorial design and response surface methodology (RSM). The statistical models developed in this study can facilitate optimizing mixture proportions of PCPC for target performance.

(Wong et al., 2020) present global dynamics of Municipal Solid Waste Incineration (MSWI) ashes research between 1994 and 2018 based on the bibliometric analysis of 1810 publications from Web of Science database. The results show rapid growth in annual publications related to MSWI ashes research, with China leading the research during study period.

(Albuquerque et al., 2021) conducted research with the following main objectives: i) to verify relative position of Brazil in the research area of substitution of aggregate of waste ii) to identify main residues used as raw material substitutes in construction industry in Brazil iii) to evaluate the hypothesis that a search using words like concrete, aggregate and residue will result in articles from the environmental and civil engineering areas.

(Abejón, 2021) presents a bibliometric analysis to review global research related to self-healing asphalt using Scopus database to look for work between 2003 and 2018. The objective was to identify relevant quantitative characteristics from the research in this period. Some important

features of the two main approaches most frequently used to develop asphalt mixtures with enhanced self-healing abilities were compiled after the review.

(Hamidi et al., 2021) conducted a scientometric study to analyze 199 global articles on 'Sponge City' indexed in Clarivate Analytics using visualization. The analysis may be of help to practitioners, policymakers, funders, editors and researchers to understand the current state of field and serve as turning point for future progress in this field.

(Xiao et al., 2021) conducted bibliometric analysis of literature in the field of recycled construction materials in pavement engineering using 3 databases (WoS, Compendex and Scopus) and VOSviewer visualization software. The results show that during the last few years researchers have paid more attention to two main approaches: i) application of rubber modified asphalt and ii) performance enhancement of recycled pavement.

(Alkhaledi et al., 2020) introduced a novel multi-criteria decision-making model to choose among various sustainable solutions to help manage storm-water. It can help decision-makers in handling storm-water by proper utilization of precipitation while ensuring public safety and by adhering to run-off regulations. It also aims to present sustainable technologies helpful in reducing storm-water overflows.

(Huang & Lu, 2018) performed a bibliometric analysis using Science Citation Index-Expanded (SCI-Expanded) database from WoS to review Urban Heat Island (UHI) research from 1991 to 2015 to statistically analyse developments, trends and directions. Author keywords were classified into i) research methods and indicators ii) generation factors iii) environmental effects iv) mitigation and adaptation strategies.

(Carpio et al., 2020) analyzed the scientific articles relating to pavements and urban heat island phenomenon. 107 articles published from 1990 to 2019 were analyzed using SciMAT tool to evaluate the general evolution in this area of science. Results show that during recent years interdisciplinary research has focused on the issues of mitigating the effects of UHI together with improving the energy performance of dwellings.

(Shah et al., 2013) reviewed the applications and engineering properties of pervious concrete pavements including environmental benefits, structural properties and durability. The research has been conducted keeping in mind that in rural areas costly storm-water management practices cannot be applied and hence cost consideration should be the primary factor to keep in mind.

(Ranjan & Alam, 2018) summarize literature on permeable pavements, highlights current trends in research and industry and recommends future areas of research and development in this field of science. The paper also looks into the possibility of use of fly ash as one of the materials for aggregate in preparing permeable pavements so as to reduce construction cost and solve fly-ash disposal problem.

(Hough, JR, 1993) reviews a number of developments that have arisen in response to the challenges that environmental problems and environmental policy pose for Cost-benefit analysis of any environmental service or action. It includes continuing progress in techniques to value environmental changes. There is a need to understand when should CBA be used in such practices and why environmental decisions are often made in manner apparently inconsistent with cost-benefit thinking.

(Johannesson & Jönsson, 1991) devoted this study to contingent valuation (CV) method and its possible area of application in health economics where in willingness to pay or willingness to accept is measured with survey methods. The development of economic evaluation in the health care area is reviewed and the existing methods (the human capital approach, cost-effectiveness analysis and cost-utility analysis) are compared with cost-benefit analysis using the CV method.

(McIntosh et al., 1999) outline recent advances in cost-benefit analysis (CBA) methods. The paper concludes saying that almost all types of economic evaluation have an element of 'cost-benefit' approach in them, but the important issue is to focus on the policy question to be addressed and to outline the relevant costs and benefits in manners that assist evaluation of welfare changes resulting from changes in the healthcare industry.

(Vickerman, 2007) reviews the problems surrounding the use of cost-benefit analysis (CBA) in the appraisal of large-scale infrastructure projects. Requirements of best-practice transport CBA have been defined and difficulties in achieving these for large-scale projects have been narrated. The main difficulties therein are forecasting over long time periods, imperfect competition in transport-using sectors to obtain estimations of wider transport benefits and introduction of private finance and appraisal network effects.

(Goggins et al., 2008) reviewed literature with the objective to arrive at a predictive Cost-benefits Analysis (CBA) model for practitioners to present a cost justification to management during planning stages. The requirement is to arrive at reliable estimates of the benefits of the ergonomic interventions. Commonly reported benefits as per results of the review are reductions in the number of work related musculoskeletal disorders (WMSDs) or their incidence rate as well as related lost workdays, restricted workdays and workers' compensation costs.

(Tang & Amon, 2013) discuss the costs and benefits of DNA copy-number alterations. Detrimental effects on health as well as benefits in increasing survival have been recorded. As the DNA copy-number alterations underlie many human diseases, the discussion of the paper ends with summing up gene-copy number changes as therapeutic targets.

(Fischhoff, 2015) reviews various developments in awareness on judgements related to formal cost-benefit analysis as well as the methods of making these judgements. The review uses examples to illustrate the issues that arise while designing, executing and interpreting such analyses. Lessons learned from the science and practice of analysis has been listed.

(Blackorby & Donaldson, 1990) present a case against the use of sum of compensating variations as a cost-benefit test. The arguments can be listed as i) ethical judgements implied by the test are not defensible, ii) positive sums of compensating variations occur without potential Pareto improvements, resulting in social preference reversals without simultaneous Scitovsky reversals, iii) when lump-sum transfers are feasible, a positive sum of compensating variations is necessary but not sufficient for Potential Pareto Improvement and iv) to eliminate preference reversals all households must have identical quasi homothetic preferences, which is not possible in real economies.

(Atkinson & Mourato, 2015) reviews developments in environmental CBA since the publication of an OECD volume on Environmental CBA by Pearce et all (2006). The direction and character of these developments evolves over time and the same is reflected in the review.

(Saad & Hegazy, 2015) extend the current Cost-benefits Analysis (CBA) to complex infrastructure fund allocation problem. The paper reviews the origins of CBA and then proposes microeconomic based heuristic approach to optimize decisions by achieving equilibrium state wherein fair and equitable allocations are made.

(Araújo et al., 2016) aim to develop a methodology based on cost-effectiveness analysis, a comparative improvement over Cost Optimal (CO) method, because it considers the investment willingness of stakeholders in the selection process of energy-efficient solutions. The method is expected to lead to selection of more desired and more energy-efficient solutions than those selected in CO method.

(Hough, JR, 1993) reviews various Cost-benefit analysis methods related to Education Cost-benefit analysis. Criticisms and benefits of various methods have been discussed. It concludes to give commentary on cost-effective analysis, alternative manpower forecasts & manpower utilization patterns and the benefits it brings to policy making on education financing.

(Rehan et al., 2018) conducted a comprehensive study to analyze and compare the life-cycle costs (LCC) of two conventional impermeable pavements (hot-mix asphalt and Portland cement concrete) and two permeable pavements (porous asphalt and pervious concrete). Alternatives were analyzed in 20 year, 30 year and 40 year analysis period. Besides the initial construction and maintenance costs, storm-water treatment costs were included in LCCA for all alternatives in areas with combined sewer and storm systems.

(Rahman et al., 2015) worked to develop a framework to identify how pervious concrete can be integrated into low volume infrastructure. The paper also summarizes the structural performance and drainage characteristics of pervious concrete parking lots constructed in various provinces of Canada, to demonstrate the viability of pervious concrete for low-volume northern applications.

(Hwang et al., 2017) assessed feasibility of pervious concrete pavement (PCP) followed by a bamboo bioretention basin (BBB) with Dracaena sanderiana for urban storm-water volume

control as well as water quality enhancement. Results showed that PCP-BBB outperformed CP-BBB not only in run-off volume reduction but also in pollutant removal.

Research Gap

Lately the research fraternity in India has also turned its attention to Pervious Concrete as a possible sustainable option for its infrastructural requirements. Out of the initial researches, some have also looked into using Fly-ash as a component of the design mix, to replace the natural aggregates used to produce pervious concrete. This takes the possible environmental benefits to the next stage.

It is important to understand the root of fly ash generation and its life cycle in the Municipal Solid Waste Management System. One of the most essential elements in the MSWM system is the Municipal Solid Waste Incineration process, which leads to the following benefits:

1. Dramatically reduce the weight and volume of MSW
2. Extend the lifespan of landfills, the last destination for waste deposition
3. Convert MSW into heat and energy for electricity generation, using state-of-art technology

Re-cycling this non-disposable waste into a material for construction can be a phenomenal feat in the practice of ‘circular economy’ as construction industry is one of the biggest contributors in non-disposable waste generation world over, while being one of the industries responsible for the depletion of natural resources to a great extent.

Hence, Fly-Ash Based Pervious Concrete might have the potential to achieve the following benefits:

1. Storm-water management
2. Ground-water replenishment
3. Recycling of non-disposable waste

Research Methodology

The study is planned to apply a mix of Qualitative and Quantitative Research methodologies so as to keep a comprehensive and holistic problem-solving approach.

The data collection from secondary source will be collected from government websites and documents, news articles as well as research articles for topics related to water scarcity, groundwater governance nationally, groundwater levels, storm-water pollution, rain-water harvesting statistics, etc. Theoretical model for Comprehensive Cost-Benefit Analysis will be created based on this data. Then for validating this model, on-field experimentation is being perceived as the ideal methodology for primary data collection. Factors to be considered for

theoretical modelling of cost-benefit analysis will also be analysed from primary data collected thorough Delphi method of data collation from expert panel.

Qualitative Research Plan:

A group of 10 to 12 field experts and industry participants will be selected keeping in mind a good balance of relevant stakeholders from the Real Estate and Construction Industry as well as Ground-water Management Governance. Individual interviews with each of them as well as a Focus Group Discussion will be will be held and analysis of the same will be performed.

Inputs from the above analysis will then be used to prepare a Quantitative Research Plan.

Quantitative Research Plan:

Relevant factors and scale for measurement of the costs involved and benefits accrued will be created. Field data will be collated for the same. The same will be used to make a detailed Cost-Benefit Analysis of the material.

Tentative Chapter Plan

Sr. No.	**Chapter Name**
1.	Introduction
	A. Background and motivation B. Research Problem and objectives C. Research Questions D. Hypotheses E. Significance of Study
2.	Literature Review
	A. Overview of urban development and sustainability B. Review of literature on pervious concrete C. Review of literature on urban development and waste water D. Review of literature on waste water management E. Review of literature on ground water discharge and its implication like water scarcity F. Review of literature on ground water recharge with pervious concrete G. Review of literature on sustainable growth Research Gap on synchronization of urban development, Waste water management and sustainable development
3.	Methodology
	A. Data sources and collection B. Variables and measures

	C. Analytical methods D. Model specification E. Hypothesis testing
4.	Results and Discussion
	A. Descriptive statistics B. Correlation analysis C. Regression analysis D. Hypothesis testing E. Discussion of results
5.	Discussion
	A. Overview of pervious concrete and its application in urban development B. Role of pervious concrete in waste water management C. Pervious concrete as a sustainable solution for urban growth D. Challenges and limitations of pervious concrete E. Future directions for research and development
6.	Conclusions
	A. Summary of findings B. Implications of theory and practice C. Limitations of the study D. Future research directions
7.	References
8.	Appendices
	A. Data sources and collection B. Data analysis and results C. Statistical tables and figures

Scope & Limitation of Research

What needs to be found out is whether the right design mix can be developed for the Indian environment and requirements keeping in mind the climatic conditions, the economic growth rate, the increasing population and construction & real estate industry. Unless the demand and supply for pervious concrete does not reach to an optimal level, its success as a sustainable infrastructure solution will remain to be a challenge, despite of the immense environmental benefits it promises to deliver. The factors impacting its demand can mainly be listed as awareness of the product, financial and operational viability and information on sourcing. The factors impacting its supply can be listed as proof of concept, raw material availability and positive market feedback. The impetus for all these factors to exist or grow can come from a detailed research aimed at making as much empirical data and market feedback available as needed for the industry leaders and first-movers to take the leap into production and deployment. If the initial market barriers were broken, pervious concrete might end up being one of the most dependable and noteworthy materials in the infrastructural development of the country. In case

the study doesn't lead to expected results towards acceptability in the market, it will certainly lead to throwing light on the gaps in the materials capability to prove as a go-to solution, leading to a list of future scope of research for a better material solution.

As the research is being conducted keeping Gandhinagar as base, the access to resources, experts and data collection from all over the country will be hindered. The on-field experiment will be conducted for a specific site; hence the validation of the theoretical model will be done for geographical, geological and topological conditions of just one small portion of one region. This may be considered as one main limitation of the study.

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